UNIVERSITY OF CALIFORNIA PUBLICATIONS

COLLEGE OF AGRICULTURE
AGRICULTURAL EXPERIMENT STATION
BERKELEY, CALIFORNIA

Factors Influencing the Development of Internal Browning of the Yellow Newtown Apple

BY

E. L. OVERHOLSER, A. J. WINKLER AND H. E. JACOB

BULLETIN No. 370

SEPTEMBER, 1923

UNIVERSITY OF CALIFORNIA PRESS
BERKELEY, CALIFORNIA
1923

FACTORS INFLUENCING THE DEVELOPMENT OF INTERNAL BROWNING OF THE YELLOW NEWTOWN APPLE

By E. L. OVERHOLSER, A. J. WINKLER and H. E. JACOB

Previous to 1905 it had been noted that apples grown in the Pajaro Valley, California, were affected by a browning of the flesh of the fruit when held in cold storage. The browning occurred while the tissue was firm and was distinct from the discoloration which accompanies breakdown of the tissues in storage from over-ripeness, or from freezing. The disease is known as "Internal Browning" and is most severe with the Yellow Newtown.

The earliest reports of loss from this trouble date from the crop of 1899.* Powell[14, 15] mentioned the browning as a storage problem. Stubenrauch[17, 18] indicated a relation between internal browning and the storage temperature. Several reports of the Bureau of Plant Industry† mention the trouble and in the report for 1920 it is stated that no relation exists between the acidity of the fruit and the browning and that as yet no definite cause can be attributed to the disease.

Recently Ballard, Magness and Hawkins[2] and Winkler[19] have published a full account of their studies of internal browning.

OBJECTS OF THE INVESTIGATIONS

The investigations reported herewith were undertaken in an attempt to determine (1) the field conditions responsible for the susceptibility of the fruit to browning and (2) the factors immediately responsible for its development in storage.

DESCRIPTION OF INTERNAL BROWNING

In Yellow Newtown apples stored at 32° F., the browning first becomes noticeable during the latter part of December. When stored at higher temperatures its appearance is delayed. At temperatures above 50° F., the disease usually does not develop.

---

* Letter from W. A. Taylor, Chief of the Bureau of Plant Industry, U. S. D. A. (1920).

† U. S. D. A. Bureau of Plant Industry Reports 1910–17–18 and 20.

The disease is non-parasitic and affects the large isodiametric cells of the pulp. It can be first detected in cross sections of the apple in somewhat elongated areas radiating outward from the central portion in the region opposite the basal end of the carpels. The areas first browned lie adjacent to and radiate outward from the primary vascular bundles.

The browning spreads most rapidly in the region of the secondary vascular bundles. It may develop well toward the calyx end, along the vascular bundles even before penetrating appreciably into the pulp laterally near the point of initial browning. The bundles themselves, however, are slow to brown. The large cells adjacent to the bundles first become affected, then the small cells and finally the bundles.

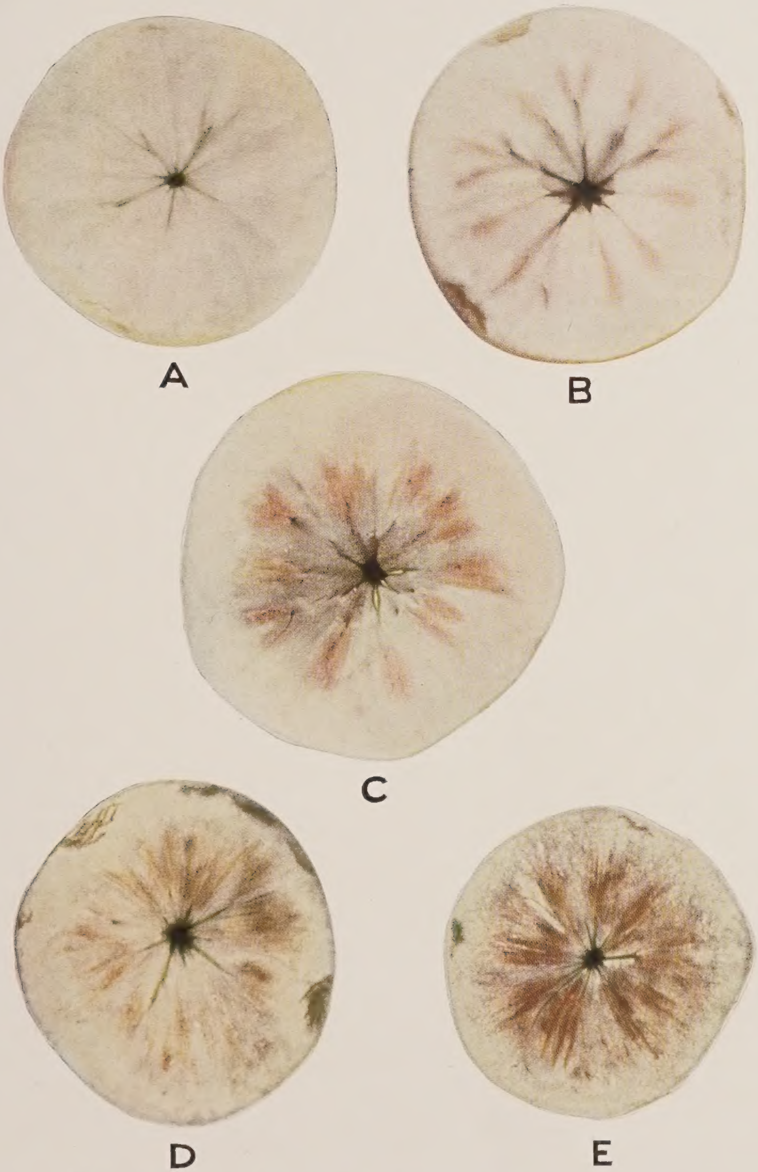
In the more advanced stages, the browning may spread throughout the pulp and resemble storage breakdown. When the development of the disease reaches an advanced stage, the small thick-walled cells of the epidermis become browned, and the fruit appears scalded. In the earlier stages, however, the epidermis appears normal, the flesh remains firm and the disease is detected only by cutting into the fruit.

METHODS OF PROCEDURE

The storage phases of the problem were conducted in the Division of Pomology cold storage plant, consisting of six rooms and two large insulated boxes. Temperatures of 30°, 32°, 36°, 40°, 45°, 57°, and 70° F., were obtained within ± 1° F., with the exception of the two higher temperatures which varied more widely. During the season of 1919 the temperature of the 32° F. room accidentally dropped sufficiently low for a short period of time to cause slight freezing of the earlier picked apples. Such fruit was discarded. The humidity in each of the different rooms was fairly constant and did not vary more than 3 to 4 per cent.

The fruit was obtained from the Rodgers Brothers Orchards,* located near Watsonville in the Pajaro Valley. The apples were packed, labeled, and shipped by express to Berkeley with minimum delay. The fruit with few exceptions represented tree-run apples. The time of harvest closely conformed to the middle of the commercial picking season, except in the case of fruit picked to determine the

* The writers are greatly indebted to Messrs. C. J. and Marion Rodgers for their interest and hearty coöperation, which enabled fruit to be obtained and certain trees to be kept under observation.



Color plate showing the degrees of internal browning recorded.
A. Normal apple. B. Trace browning. C. Slight browning. D. Bad browning.
E. Very bad browning.

effect of maturity when harvested. For this purpose the earliest picking was made as the regular picking began, the second about the middle, and the third at the close of the harvesting season. Each lot represented fruit from a single tree.

Upon receipt at the storage plant, the lots were divided into the necessary number of sub-lots for the particular experiment. The sub-lots of from 80 to 100 specimens each were stored in apple boxes. The boxes were placed so that sufficient space was maintained for normal ventilation in storage. Apples of the same lot were used in each experiment and check, and as nearly identical conditions as possible were maintained except for the factor being tested.

Since internal browning affects the flesh of the fruit it was necessary to cut the apples in order to make the observations. Browning could be best detected by cutting perpendicular to the axis of the core in a plane passing through the junction of the carpels with the stem.

Four observations were made each season at monthly intervals, beginning in January. Twenty specimens from every sub-lot were cut at each of the four seasonal observations. By cutting several hundred specimens from time to time it was determined that the error in cutting only twenty specimens ranged from 2 to 5 per cent, and this error was reduced when the four seasonal cuttings were averaged.

Definition of terms.—The terms employed in recording the observations to designate the degree of browning are defined as follows:

1. *Normal.*—Apples in which no browning was apparent to the unaided eye (fig. 1.)

2. *Trace Browning.*—When browning was present in the flesh to a recognizable degree, but not of sufficient severity to lessen the market value (fig. 2).

3. *Slight Browning.*—When browning was sufficiently severe to lessen the market quality, but not to such a degree as to render the apples objectionable for culinary purposes (fig. 3).

4. *Moderate Browning.*—When the fruit was rendered unsuitable for ordinary culinary purposes (fig. 4).

5. *Severe Browning.*—When the structure of the tissue exhibited a marked degree of disintegration, and gave the apples an appearance, upon cutting, of being rotten within (fig. 5).

I. The Relation of Orchard Conditions to the Development of Internal Browning in Storage

The Relative Severity of Internal Browning of Yellow Newtown Apples Grown in the Pajaro Valley and Elsewhere

In order to determine whether the browning was confined solely to apples grown in the Pajaro Valley, California, apples were obtained from other localities in the state and even from districts in other states where the Yellow Newtown is successfully grown. The fruit was shipped by express to Berkeley and stored throughout the season under similar conditions at 32° F. The results are shown in table 1.

TABLE 1

The Occurrence and Intensity of Internal Browning of Yellow Newtown Apples Grown in Various Districts

Season	Source of fruit	Degree of browning				
		Per cent normal	Per cent trace	Per cent slight	Per cent moderate	Per cent severe
1919	Oakglen, Cal. Foothills of southern California	80	20	0	0	0
1919	Mariposa Mts. Foothills of Sierras	100	0	0	0	0
1919 and 1920	Ben Lomond, Cal. Hills bordering Pajaro Valley	97	3	0	0	0
1919	Oregon Agricultural Experiment Station, Willamette Valley	95	5	0	0	0
1919 and 1920	Cornell Agricultural Experiment Station, Western New York	50	42	8	0	0
1920	Dutchess Co., New York, Hudson River Valley	100	0	0	0	0
1920	Albemarle Co., Virginia	95	5	0	0	0
1919 and 1920	Pajaro Valley, California	5	20	22	33	20

These figures indicate that Yellow Newtown apples are generally susceptible to internal browning. The disease in apples from other regions than the Pajaro Valley, however, has not been sufficiently severe to render it an economic problem.

The fact that the apples from nearly all sections showed browning indicates there is either something peculiar to the variety which makes it susceptible to browning, or that the trouble lies in the regions in which it is at present most extensively grown. Both of these conditions appear to be more or less responsible for the browning. The fact that other varieties of apples grown in the same districts, with the exception of the Pajaro Valley, are immune to this disease would, at least, suggest that the Yellow Newtown exhibits a varietal characteristic of susceptibility to internal browning.

The effect of the region in which the fruit is grown upon its susceptibility to browning is indicated by the fact that several additional varieties of apples, as the Yellow Bellflower and the Red Pearmain, which show no tendency to browning in other sections, become susceptible to this disease when grown in the Pajaro Valley. Furthermore, the Yellow Newtown, when grown in this valley is more susceptible to internal browning than when grown elsewhere. Mackie,[11] as a result of a soil survey of the Pajaro Valley, is of the opinion that the susceptibility to the disease is not due to soil conditions. The climatic conditions of the Pajaro Valley, therefore, apparently exert an influence upon the development of apples which have not been shown to similarly occur elsewhere, and which render them susceptible to this disease.

The Relation of the Age of the Tree to Internal Browning

The belief has been expressed by growers and by cold storage men, that fruit from young, vigorous trees, just coming into bearing, is more subject to internal browning than fruit of vigorous trees, well advanced into the productive period. To test this opinion, a storage experiment was started in 1918 to determine the relation of the age of the trees to the browning of the fruit. For each of the five storage seasons during which observations were made upon this phase of the problem, the same trees were compared. The old but vigorous trees were in the prime of their productiveness, while the young vigorous trees were just coming into bearing at the time this work was started. Table 2 represents four seasons' average of the per cent of internal browning for all the lots of the old and the young trees, respectively.

These data indicate a slight relation between age of trees and internal browning. The authors believe, however, that differences in the maturity of the fruit from the old and the young trees when picked, may affect the degree of browning to a certain extent. The fruit collected from the old trees was, as a rule, earlier in ripening

than that from the young trees. The maturity of the fruit when harvested is shown later to affect the relative degree of browning. Furthermore, the vigor of vegetative growth as affected by age of tree would also influence the degree of browning.

TABLE 2

THE EFFECT OF AGE OF TREE UPON BROWNING OF APPLES

Age of trees	Seasons averaged	Number of boxes tested	Average degree of browning				
			Per cent normal	Per cent trace	Per cent slight	Per cent moderate	Per cent severe
Old	1918 to 1922, inc.	25	25	32	18	15	10
Young	1918 to 1922, inc.	25	33	31	10	14	12

THE RELATION OF SIZE OF CROP BORNE BY THE TREE TO INTERNAL BROWNING

During the seasons of 1918 to 1921, inclusive, fruit was harvested from trees bearing a full crop and from trees bearing a light crop to determine the effect of the size of crop being matured by a tree upon the susceptibility of its fruit to browning. The fruit was stored at 32° F. and the average per cent of normal and brown fruit for the three years is given in table 3.

TABLE 3

THE RELATION OF SIZE OF CROP BORNE BY THE TREE TO INTERNAL BROWNING

Extent of crop per tree	Number of boxes tested	Per cent normal fruit	Per cent browned fruit
Light	27	15	85
Heavy	18	70	30

The data indicate that the fruit from trees bearing a heavy crop is less susceptible to browning in storage than fruit from trees bearing a light crop.

This is substantiated by the fact that tree No. 9 had a medium crop in 1918–19 and the fruit showed 40 per cent browning, but in 1919–20 and 1920–21 the crops borne were very heavy and during those years no browning occurred. Tree No. 10 had a moderately heavy crop in 1918–19 and during the two following seasons produced crops successively lighter. The percentages of fruit showing browning during those years were 35, 50 and 55, respectively.

THE RELATION OF THE VIGOR OF THE TREE TO INTERNAL BROWNING

Tests concerning the relation of tree vigor to internal browning were begun during the season of 1917–18. Five years' data are available in comparing very vigorous with weak trees, and this is contrasted with four years' data obtained from moderately vigorous trees. The fruit was stored at both 32° F. and 36° F., but the data presented in table 4, represent the averages of both temperatures for all years.

TABLE 4

RELATION OF TREE VIGOR TO INTERNAL BROWNING

Vigor of trees	Number of seasons averaged	Number of boxes tested	Average degree of browning				
			Per cent normal	Per cent trace	Per cent slight	Per cent moderate	Per cent severe
Very vigorous	5	30	25	43	11	11	10
Moderately vigorous	4	25	64	24	5	3	4
Weak	5	30	20	36	18	15	11

These data show that apples from trees of very low vegetative vigor brown considerably more than those from trees of moderate or normal vigor. Furthermore, apples from trees of unusually high vigor produce fruit less resistant to browning than that produced by trees of normal vigor.

During the season of 1921 fruit was harvested at the three different stages of maturity from a tree having several branches which were suffering from sunscald and disease, making practically no new terminal growth, and which possessed scanty foliage, deficient in chlorophyll. Other portions of the same tree had vigorous growing branches possessing abundant dark green foliage from which fruit was also harvested. The fruit was stored at 32° F. for five months, and the results which substantiate those previously presented are given in table 5.

TABLE 5

THE RELATIVE BROWNING OF FRUIT FROM WEAK AND VIGOROUS BRANCHES UPON THE SAME TREE (1921)

Vigor of branches	Number of boxes	Average degree of browning				
		Per cent normal	Per cent trace	Per cent slight	Per cent moderate	Per cent severe
Vigorous	3	38	21	20	19	1
Weak	3	29	28	27	16	0

The Relation of Maturity of Fruit When Harvested to Internal Browning

Powell and Fulton,[14] Brooks, Cooley and Fisher,[4, 5, 6] and others have emphasized the importance of the maturity of the fruit when harvested, in the control of certain non-parasitic diseases of the apple. Cold storage managers have believed that the occurrence of internal browning was partially due to an immature condition of the apples when stored; and apples permitted to remain on the trees until they had a higher sugar content, according to these men, were more resistant to browning.

An investigation of the relation of the maturity of the fruit to internal browning was conducted during the seasons of 1919 to 1921, inclusive. Three pickings of fruit were made each season. The fruit of the first picking was "hard green" in maturity and of a solid green color; that of the second picking was "firm green" and signs of the yellow color were becoming evident; while the fruit of the last picking was somewhat "over-ripe" for harvesting and showed considerable yellow color over the entire surface. The fruit for each lot was taken from the same trees at each of the pickings. Uniformity of the lots was obtained by taking fruit from all portions of the tree at each picking. The apples of each tree for the several pickings were stored under identical conditions at 32° F. and 36° F. The average results of three season's observations are given in table 6.

TABLE 6

Relation of Maturity of Fruit to Internal Browning

Period of harvest	Number boxes testes	Average degree of browning				
		Per cent normal	Per cent trace	Per cent slight	Per cent moderate	Per cent severe
Early	36	42	31	12	10	5
Medium	27	31	38	15	14	5
Late	27	15	35	25	18	7

These figures show a definite relation of maturity of the fruit at time of harvest to susceptibility to internal browning, the more mature fruit browning more severely in every test. The mature fruit not only browned more severely, but developed the disease more rapidly. This fact is shown in table 7, which represents the averages for all the lots of each picking for the season of 1920–21.

TABLE 7

THE RELATION OF MATURITY OF THE FRUIT TO THE RATE OF DEVELOPMENT OF BROWNING

Temperature of storage	Date of picking	Date of storage	Time in storage	Per cent of marketable* and unmarketable fruit	
				marketable	Unmarketable
32°F.	Nov. 6	Nov. 16	6 weeks	61	39
32°F.	Oct. 16	Oct. 19	15 weeks	62	38
32°F.	Sept. 26	Sept. 26	20 weeks	60	40

* Marketable fruit included both "normal" and the "trace browned" specimens; unmarketable included "slight," "moderate" and "severely browned" specimens.

The apples picked latest, browned approximately two and one-half times as rapidly as those picked in the middle of the normal harvest period. Fruit picked in the middle of the season browned about one and one-third times as rapidly as that picked at the beginning of the harvest period.

The total sugar content as determined by chemical analysis at the time of harvest of the fruit picked September 26, October 16, and November 6, was 9.4, 10.0 and 11.4 per cent, respectively. This shows that a higher sugar content does not inhibit browning. In fact Winkler[19] found by analysing a large number of samples, that the sugar content did not influence the resistance or susceptibility of the fruit to the disease.

Ballard, *et al.*,[2] in their summary state that apples high in sugar and acid content tended to become browned to a much greater extent than normal fruit. Winkler[19] found that decrease in total acidity did not influence the resistance of the fruit to browning. He determined that although the titrable acidity decreased with maturity and subsequent storage, the active acidity, as indicated by the pH value of the expressed juice, remained practically constant.

THE EFFECT OF ORCHARD TEMPERATURE UPON INTERNAL BROWNING

Many of the leading fruit men of the Pajaro Valley attribute the occurrence of internal browning to the cold foggy weather which usually prevails during the latter part of July and August, at the time the fruit is growing most rapidly.

With these observations as a basis, experiments were started in the spring of 1920 to determine the effect of orchard temperature and fog upon internal browning. During the first week of May, 1920, a tent was erected over a single average tree which bore a normal set of

fruit. A framework was built over the tree and covered with black cambric cloth to within about six feet of the ground. Thus, all the branches with fruit were shaded continuously. At the top on the north side, a six-inch strip extending the entire length of the tent was left open, which permitted a good ventilation of the tent. Otherwise, this tree was given the identical treatment as the remainder of the orchard. At the same time the tent was erected, 100 individual apples on an adjacent tree were placed in black cloth bags. A similar number of apples on adjoining trees were placed in black bags on the first of June and July, respectively.

During the season of 1921 the experiment was repeated, except that two tents were constructed over separate trees and in one of the tents two oil stoves, with accessory oil tanks were kept burning continuously throughout the season until two pickings had been obtained in the fall, when the tent was accidentally destroyed by fire. Furthermore, apples were enclosed in white as well as in black bags. One hundred specimens each were placed in both the white and black bags upon the following dates: May 10, June 10, July 15, and August 26.

Owing to the lack of necessary equipment, it was impossible to measure the exact effect of the tent and black bags upon the light intensity. Nevertheless, it is thought that the light exclusion, as such, was negligible, since it had little or no effect upon the amount of browning as shown by table 8.

This indication as to the unimportance of the decreased light intensity of the valley because of fogs, is confirmed by the graphs in chart 1,* which represent the total number of cloudy and partly cloudy days for the Pajaro Valley, California; Albermarle County, Virginia; and the Rogue River Valley, Oregon. These localities are among the most important regions in the production of the Yellow Newtown apple. The graphs show that in Virginia where the apples do not brown, there are approximately the same number of cloudy and partly cloudy days for the months concerned as there are in the Pajaro Valley where browning is a serious problem. In the Rogue River Valley, where browning also is not a problem, there are a few cloudy days. It is questionable, however, as to whether or not this factor has any appreciable direct effect upon the resistance of the apple to this disease as will be brought out later in the relation of temperature to browning. The number of cloudy or partly cloudy days would exert an indirect effect by influencing the temperature of the atmosphere and to a greater degree of the fruit (table 8).

* Records from Climatological Data Reports. U. S. Dept. of Agr. Weather Bureau, 1905 to 1920.

The effect of the tent and black bags upon the temperature was very striking. The daily mean temperature at the core of the fruit in black bags as indicated by self-recording thermometers, was nearly 10° F. higher than that of apples normally exposed. In case of the tented tree, a lower mean temperature was maintained by the shading and lack of circulation of the air. Here the temperature, as recorded by accurately regulated thermographic instruments, was found to be about 5° F. lower than the air temperature.

CHART 1

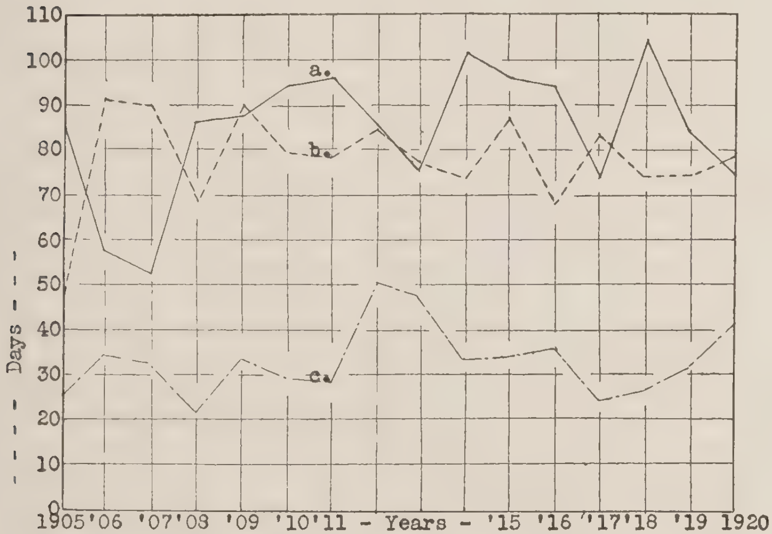


Chart 1.—The total number of cloudy and partly cloudy days for June, July, August, and September for *a*, Pajaro Valley, California; *b*, Albermarle County, Virginia, and *c*, Rogue River Valley, Oregon.

The fruit outside the tents had an average higher temperature than the air temperature, as a result of heat absorption during periods of sunshine. The fruit under the tents had a temperature practically identical with the air temperature of the tent. These temperature differences emphasize the effect of sunshiny days as contrasted with foggy or cloudy days. On foggy days the fruit not tented, regardless of the treatment given, approached the temperature of the open air. When the sun was shining, however, the temperature of exposed fruits averaged nearly ten degrees higher than air temperature.

TABLE 8

THE EFFECT OF ORCHARD TEMPERATURE UPON INTERNAL BROWNING

Treatment	Average temperature sun	Number readings	Average temperature shade	Number readings	Average temperature foggy days	Number readings	Average night temperature	Number readings	Number seasons average	Average degree of browning				
										Per cent normal	Per cent trace	Per cent slight	Per cent moderate	Per cent severe
Black bags	88.1 F	43	72.3	52	67.6	11	59.3	8	2	84	9	4	3	0
White bags	79.5 F	48	66.5	37	64.9	10	58.6	8	1	26	24	21	18	10
Normally exposed apples	78.9 F	34	66.5	34	63.3	8	57.3	8	2	28	28	24	16	4
Heated tent	71.7 F*	18							1	20	55	20	5	0
Unheated tent	69.5 F*	19							2	12	14	38	31	5
Air temperature	71.6 F	44	64.9	40	61.1	6	55.4	8	1					

* Average temperature throughout the growing season.

The bagged fruit and checks from similar positions on the same trees were harvested at the first two pickings. The fruit from the tented tree, with fruit from two adjacent trees for checks, was also harvested at these first pickings. All of the lots and checks were stored under identical conditions at 32° F. The results of these experiments are given in table 8. As all the bagged fruit behaved similarly, only the average for all the lots is given. The same is true for the fruit of the tented tree and the checks.

CHART 2

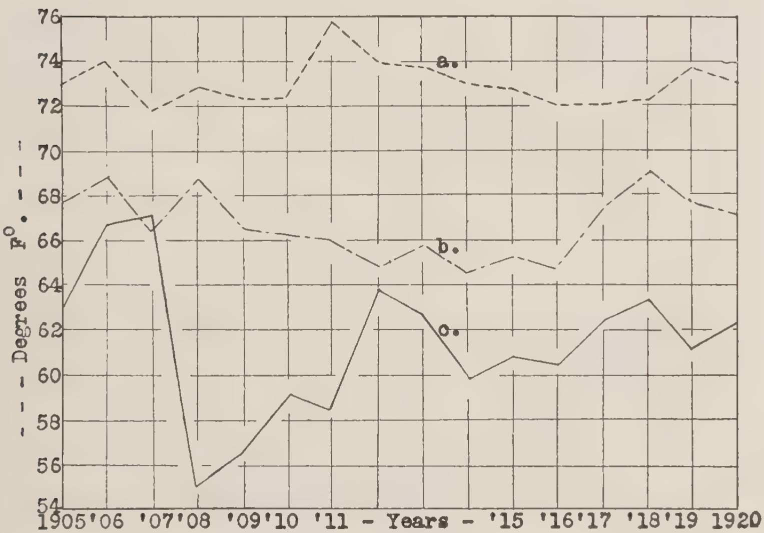


Chart 2.—The average temperature for June, July, August, and September for *a*, Albermarle County, Virginia; *b*, Rogue River Valley, Oregon, and *c*, Pajaro Valley, California.

These data indicate a definite relationship between the orchard temperature and internal browning. A daily mean temperature of about 9° F. above the temperature of the normally exposed fruit in the orchard reduced the browning to a marked degree. Conditions which resulted in the fruit temperatures being below that of normally exposed fruit materially increased the amount of browning.

This relation between orchard temperature and the amount of browning becomes more impressive when the temperature records of this valley are compared with the years of severe and of moderate or no browning for this region, and with the temperature records of other

districts where this variety of apple grows satisfactorily, but where the browning is not a problem. The graphs in chart 2* represent the mean temperature for June, July, August and September for the Pajaro Valley, California; Albemarle County, Virginia; and Rogue River Valley, Oregon. If the record for the Pajaro Valley is observed, it will be seen that in 1908 and in 1914, years in which very heavy losses through internal browning occurred, the mean temperature for these four months was very low. For 1915 and 1916, respectively, when the mean temperature for these growing months was nearer the normal value, the severity of the browning was also less. In 1912, 1913, 1917 and 1918, years of higher mean temperature for the months of rapid growth, however, there was little or no browning in the commercial storage plant. Comparing the temperature records of the Pajaro Valley with those of Rogue River Valley, Oregon and Albemarle County, Virginia, it is found that these regions have a mean temperature of 5° F. and 11.6° F. higher, respectively, than that of the Pajaro Valley.

The Effect of Exposure (Position of the Fruit on the Tree) Upon Internal Browning

Results which further confirm this relation of orchard temperature to browning were obtained by collecting fruit from well exposed and shaded portions of the tree. During the seasons of 1920 and 1921, fruit was collected from the upper southwest periphery of two trees, where the fruit received the maximum effect of the sun's rays, and also from the lower north part of the same trees where the fruit was continuously in the shade. The lots were stored under identical conditions at 32° F. The results are given in table 9.

TABLE 9

The Effect of Exposure Upon Internal Browning

Position of fruit on tree	Average fruit temperature during day	Number of seasons averaged	Average degree of browning				
			Per cent normal	Per cent trace	Per cent slight	Per cent moderate	Per cent severe
Well exposed on S. W. periphery of tree	81°F.	2	42	44	11	3	0
Shaded interior N. side of tree	67°F.	2	22	43	22	12	1

* Records from Climatological Data Reports. U. S. Dept. of Agr. Bureau, 1905 to 1920.

These figures show nearly twice as much browning in fruit from the same trees when picked from the shaded portions as contrasted with the exposed portions. Temperature records show that during the day the temperature of the well exposed fruit averaged about 14° F. higher than that from the shaded side of the tree.

THE RELATION OF SELF- VS. CROSS-POLLINATION TO INTERNAL BROWNING (1919–20)

In the spring of 1919, in connection with the pollination experiments, a single Yellow Newtown tree was enclosed in an insect-proof mosquito-bar tent, in which was placed a hive of bees. As a result, all the fruit that set was from self-pollination. A Yellow Newtown and a Yellow Bellflower tree were also enclosed, together, within a single tent containing a hive of bees. A very heavy set of Yellow Newtown resulted and it was assumed that a large percentage of these were cross-pollinated fruits. In addition the Yellow Newtown was selfed and crossed with Yellow Bellflower by hand. The data are presented in table 10.

TABLE 10

RELATION OF SELF- VS. CROSS-POLLINATION TO INTERNAL BROWNING (1919–20)

Pollination	Number specimens	Average degree of browning				
		Per cent normal	Per cent trace	Per cent slight	Per cent moderate	Per cent severe
Yellow Newtown—Selfed	225	28	54	14	4	0
Yellow Newtown x Yellow Bellflower	220	15	25	27	24	9

The results are not sufficiently conclusive to state that cross-pollination increases the susceptibility of the Yellow Newtown to internal browning, but they strongly indicate at least that provision for cross-pollination cannot be expected to decrease the susceptibility of this variety to internal browning.

II. The Relation of Storage Conditions to the Development of Internal Browning

The Effects of Delayed Storage Upon Internal Browning

The Yellow Newtown apple of the Pajaro Valley tends to drop prematurely; hence the fruit is harvested in a more immature state than is the practice with this variety elsewhere. Experiments designed to test the effect of delayed storage were conducted during the seasons of 1919 and 1920 by permitting the fruit to ripen at room temperature for one month before storing at 32° F. The fruit was kept in open boxes throughout the experiments. The results of the tests are given in table 11.

TABLE 11

The Effect of Delayed Storage Upon Internal Browning

Treatment	Number of boxes	Average degree of browning				
		Per cent normal	Per cent trace	Per cent slight	Per cent moderate	Per cent severe
Storage delayed four weeks	9	16	36	27	12	9
No delay in storage	9	37	37	12	8	6

The amount of internal browning was greatly increased by the delayed storage in all of the tests. This increase is possibly due to the fact that delayed storage resulted in the fruit being more mature when placed in cold storage. Experiments with maturity of fruit show conclusively that the more mature the fruit, the more susceptible it is to internal browning. The data emphasize the necessity of quickly placing the fruit in storage at the proper temperature.

The Effect of Intermittent Storage Upon Internal Browning

Experiments were conducted to determine the effect of intermittent storage upon internal browning. Apples of the first and second pickings from the same trees were employed during the seasons of 1919 and 1920. One portion of each lot was left continuously in storage at a temperature of 32° F.; another portion was removed to room temperature for 24 hours every two weeks; and a third portion was removed to room temperature for 48 hours once each month. There was, however, no appreciable difference between the two types of intermittent storage, hence, they are averaged together in the data presented in table 12.

TABLE 12

THE EFFECT OF INTERMITTENT STORAGE UPON INTERNAL BROWNING

Treatment	Number of boxes	Average degree of browning				
		Per cent normal	Per cent trace	Per cent slight	Per cent moderate	Per cent severe
Intermittent storage	5	15	36	26	14	8
Continuous storage	5	21	32	21	16	10

These data show no promise of controlling internal browning by the practice of intermittent storage, and emphasize the advisability of keeping the fruit continuously in storage until placed upon the market.

THE EFFECT OF STORAGE TEMPERATURE UPON INTERNAL BROWNING

Investigations by Powell and Fulton[14] indicated that all apples could be best stored at about 32° F. Losses, however, were incurred through the browning of Pajaro Valley grown Yellow Newtown apples when stored at this temperature. Through the work of Stubenrauch[17] Pajaro Valley apples have been stored at 36° F. since about 1910. Ballard, *et al.*,[2] state that browning can be largely prevented by storing Pajaro Valley apples at 36° F. to 38° F.

In the experiments of the authors, apples from the Pajaro Valley were stored at 32° F. and 36° F. for five seasons and it was found that considerable browning occurred after February 1, even in the fruit stored at 36° F. Aside from the browning, however, the apples stored at 36° F. kept satisfactorily each year. Apples were, therefore, stored at various degrees of temperature above 36° F., with the following objects: (1) To determine the lowest temperature at which internal browning will not develop during the normal storage period. (2) To determine whether or not the temperature which is sufficiently high to prevent internal browning is also sufficiently low for practical storage purposes.

The averages, after five months storage each season, for all the lots at each of the temperatures for the season during which the respective temperatures were available, are recorded in table 13.

TABLE 13

THE EFFECT OF STORAGE TEMPERATURE UPON INTERNAL BROWNING

Storage temperature	Number seasons average	Number boxes tested	Degree of browning				
			Per cent normal	Per cent trace	Per cent slight	Per cent moderate	Per cent severe
30°F.	2	6	10	26	24	25	15
32°F.	5	15	15	25	21	25	14
36°F.	5	15	35	37	16	9	3
40°F.	2	6	74	23	3	0	0
45°F.	3	9	95	5	0	0	0
57°F.	1	3	100	0	0	0	0
70°F.	2	6	100	0	0	0	0

The results obtained show a definite relation between the amount of internal browning and the storage temperature. The effect of a few degrees is striking. Browning did not occur in any of the fruit stored at a temperature of 57° F. or above.

Practically no browning occurred at 45° F. and the fruit remained marketable when stored at 40° F. in that, as used by the writers, the term ''trace browning'' was not considered sufficient to lessen the marketability of the fruit.

Apparently internal browning does not occur at a temperature which is but few degrees above those used in the commercial storage of apples. The question naturally arises as to whether or not apples can be stored successfully at this slightly higher temperature. The Yellow Newtown is one of the best keeping apples. It is commonly stored in basements and similar facilities of the home. The writers have observed apples which were held in basement storage until the middle of April without loss. In the case of the fruit stored in the laboratory (room temperature) during 1919–20 and 1920–21, no loss through rot occurred until after March 1. This fruit kept well despite the fact that the temperature in the laboratory fluctuated considerably and at times, when the room was closed, became rather high. In the storage plant, all the fruit kept in good condition throughout the normal storage period, which ends about the middle of April for this variety. One shipment of fruit, however, was in a train wreck and developed considerable rot at all the temperatures, the amount of rot being greatly increased by only a few degrees rise in temperature.

Thus it would appear, that where sound fruit is used and prompt storage under uniform conditions is possible, the fruit can safely be held at temperatures sufficiently high to prevent browning without other forms of deterioration developing. In commercial practice, however, it would probably not be expedient to store apples for any prolonged period of time above 40° F. It should, nevertheless, be advisable to store the apples at or just below this temperature, since the browning developed at 40° F. was very mild, rarely exceeding the condition classed as ''trace browning.'' Thus it would seem possible to keep this variety of apple satisfactorily throughout its normal storage season by storing at a temperature sufficient to retard the development of the usual forms of deterioration and prevent any browning that would interfere with its saleability.

The browning was not only increased in severity as the temperature decreased below 40° F., as shown by the figures in table 13, but its development was also more rapid. This correlation of temperature of storage with the time of initial appearance and the subsequent development of the browning is illustrated by the graphs in chart 3. The apples stored at 32° F. showed browning a month prior to its detection in the fruit stored at 36° F., and the apples held at 40° F. remained normal for almost two months after those stored at 36° F. had begun to brown.

CHART 3

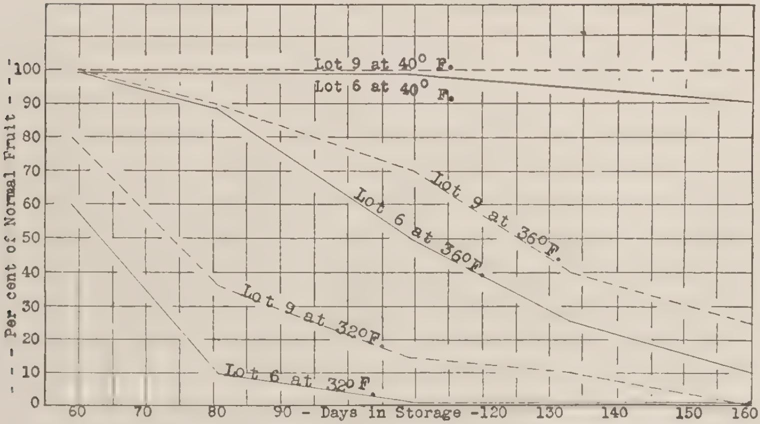


Chart 3.—The effect of temperature on the rate of development of internal browning.

The Effect of Carbon Dioxide and Oxygen Upon the Development of Internal Browning

Carbon Dioxide.—One of the most common opinions with regard to internal browning is that its development results from the accumulation of carbon dioxide in the storage room. To determine the validity of this opinion, apples were placed in approximately 90 per cent carbon dioxide for varying intervals of time. All the lots were then stored in ordinary apple boxes at 32° F. until the final observations were made. The results of these tests are given in table 14.

TABLE 14

The Effect of Carbon Dioxide Upon the Development of Internal Browning

Treatment and time stored	Degree of browning				
	Per Cent normal	Per cent Trace	Per cent slight	Per cent moderate	Per cent severe
1. Check—no treatment stored 8 weeks	50	50	0	0	0
2. In carbon dioxide for 8 days; stored 8 weeks	90	10	0	0	0
3. Same as (1), but stored 12 weeks	20	70	10	0	0
4. In carbon dioxide for 12 weeks	50	50	0	0	0
5. In carbon dioxide for 14 days; stored 12 weeks	70	30	0	0	0

These results show that the accumulation of carbon dioxide does not necessarily render the fruit more susceptible to the browning. In fact, the treatment with the gas appeared to inhibit the development of browning.

The apples that were held in the carbon dioxide for 14 days developed a disagreeable alcoholic taste. Beyond the development of this taste, however, they remained apparently normal. Apples which were placed in the gas for a short length of time exhibited some resistance to the browning but still retained their normal flavor.

Other apples were stored in approximately 40 per cent carbon dioxide in sealed containers for 8 weeks. No browning developed in this fruit while it remained sealed in the cans, but upon being exposed to the air it browned throughout. This indicates that even at this per cent, when inclosed, the carbon dioxide markedly affected or injured the tissues; hence, as soon as the apples came in contact with air the cells browned through the process of oxidation.

Oxygen.—As the apple carries on metabolic activities while stored, the question arises as to whether its behavior with regard to internal browning may not be affected by the restricted oxygen supply in storage. To test the effect of an increased oxygen supply, some apples were stored in sealed containers of normal air, while others were placed in containers in which the oxygen content was kept above that of normal air. The results of these tests are given in table 15.

TABLE 15

THE EFFECT OF AN INCREASED OXYGEN SUPPLY UPON THE DEVELOPMENT OF INTERNAL BROWNING

Treatment and time stored*	Degree of browning				
	Per cent normal	Per cent trace	Per cent slight	Per cent moderate	Per cent severe
1. Check—in normal air—stored 6 weeks	0	20	35	38	8
2. In 40 per cent oxygen stored 6 weeks	0	29	26	45	0
3. Check—in normal air—stored 8 weeks	40	30	20	10	0
4. In 40 per cent oxygen stored 8 weeks	40	50	10	0	0
5. In 40 per cent oxygen stored 8 weeks	30	35	25	10	0
6. In 70 per cent oxygen stored 8 weeks	0	20	25	35	20

* Apples sealed in cans.—The apples used in tests 1 and 2 were from different lots than those used in tests 3, 4, 5 and 6.

These figures show that an increase in the amount of oxygen above that of normal air has little or no effect upon the development of browning. In the last test where the amount of oxygen was very high, the fruit ripened rapidly and the skin showed signs of serious injury. Not even in the cases where the tissues themselves escaped injury was the difference in the amount of browning sufficient to be indicative of any control of the disease by an increased oxygen supply. These results are in decided contrast to the uniformly beneficial effects of air circulation which are reported in a later section of this paper.

THE RELATION OF ESSENTIAL OILS TO INTERNAL BROWNING

Dixon and Atkins[7] have shown that anaesthetics increase the permeability of the plasma membrane, for the cell sap is readily expressed after their application. When applied for this purpose, however, the anaesthetics were toxic and their effect irreversible. Osterhout[12] in

his work with anaesthetics made measurements upon tissue to determine whether the increase in permeability, usually observed to follow their application, is due to the anaesthetics or to toxins. He concludes that the anaesthetics produce a decrease in the permeability which is reversible and that the subsequent increase in permeability is due to the accumulation of toxic substances as a results of the action of the anaesthetics. In 1910 Armstrong[1] and his co-workers showed that under the influence of anaesthetics and certain other substances which they called hormones, reactions occur in the cells which indicate that the enzymes and their substrati were brought into contact. Among the results of this mixing of the enzymes and substrati, as observed by these workers, was an oxidation which resulted in pigmentation. These workers also state that these phenomena are constantly taking place in the plant, but under normal conditions their products are passed off before they become injurious. Under abnormal conditions, however, they may accumulate in sufficient amount to greatly hinder the activities of the tissues and eventually to cause the death of the cells.

Giglioli[8, 9] found that essential oils markedly influence the movement of water, enzymes and soluble substance through the cell membrane, owing to the rapid change in the permeability in the plasma membrane. Recently Pantanelli[13] has shown that the cells of the endocarp of the mandarin orange (*Citrus nobilis*), when subjected to temperatures very near to freezing, suffer a progressive increase in the cell permeability. The increase in permeability was favored by substances that penetrate rapidly into the cells.

In 1920, Power and Chestnut[16] isolated the essential oils of the apple. They demonstrated conclusively that essential oils are being produced continuously by the apple in sufficient quantities to be detected. Brooks, Cooley and Fisher[4, 5, 6] found that apple scald, a non-parasitic storage disease which is generally confined to the surface of the fruit, was apparently due to volatile substances which are produced by the fruit when held for sometime under the more or less abnormal condition of storage. As proof of this contention, they present data which show that the disease is reduced by removing these volatile substances from the fruit by air circulation or by storing the fruit in wax or oil wrappers that are good absorbents of essential oils.

After making a considerable number of observations upon the appearance of the advanced stages of apple scald and upon internal browning, the condition of the tissue and the way in which these diseases spread into the flesh of the fruit, it became apparent that there was a similarity between these two storage troubles. Histological examinations of affected tissues further emphasized the analogy which

existed between these diseases. There was no regularity about the spread of the disease from one cell to the other in the tissue, since isolated cells showing browning were always found to be scattered among the normal cells near the region of scald or browning. In the cells in which the progress of the browning could be followed, it was found to be identical in the two diseases, the browning starting at the periphery of the cell in the vicinity of the nucleus, and from there spreading to all parts of the cell. Plasmolysis accompanied the advance in browning, until in the severe stages the protoplast occupied only a small fraction of the cell cavity. The cell wall remained unchanged. In order to further test this apparent similarity between the two diseases, experiments with treatments which had proved successful in reducing the amount of apple scald, were conducted to determine their effectiveness in the control of internal browning.

AIR MOVEMENT AS A PREVENTIVE OF INTERNAL BROWNING

During the seasons of 1919–20 and 1920–21 apples stored at 32° F. were placed in slat boxes and subjected to forced air circulation before an electric fan for 10 to 20 minutes twice each week. One-half of these apples were wrapped in commercial wrappers while the other half were packed without wrapping. As a check, apples of the same lots in common storage were used. In addition to these tests apples were also sealed in tin cans provided with inlet and outlet openings, and subjected to a slow continuous air circulation maintained by an aspirator. Apples with and without wrappers were again employed in these tests. A summary of the results is given in table 16.

TABLE 16

THE EFFECT OF AIR MOVEMENT ON THE DEVELOPMENT OF INTERNAL BROWNING

Condition of storage	Number of tests	Temperature of storage	Degree of browning				
			Per cent normal	Per cent trace	Per cent slight	Per cent moderate	Per cent severe
Apples in common storage	4	32°F.	24	63	10	3	0
Apples ventilated by air circulation, wrapped	4	32°F.	54	42	4	0	0
Apples ventilated by air circulation, not wrapped	4	32°F.	86	14	0	0	0

The effect of air circulation on the development of the browning is striking. The figures also show a relation between the effectiveness of the ventilation and the severity of browning for, in every case the wrapped fruit exhibited more browning than that not wrapped. This reduction by ventilation in the amount of browning indicates that the trouble is favored by the accumulation of deleterious substances which are removed by air movement.

Gas Absorbents as Agencies in the Prevention of Internal Browning

On January 5, 1920, sixty specimens each of representative portions of the fifteen lots harvested during the first and second pickings of the 1919 season were wrapped with oiled wrappers. Apples of the same lots in common storage were used as checks. At the time of the first two pickings for the 1920 season eighty specimens each of two lots were again stored in wrappers impregnated with different oils. A summary of the oils used and the results obtained with these treatments at 32° F. is given in table 17.

TABLE 17

The Effect of Gas Absorbents on the Development of Internal Browning

Treatment	Number of tests	Number of apples used	Degree of browning after 2½ months storage				
			Per cent normal	Per cent trace	Per cent slight	Per cent moderate	Per cent severe
Olive oil wrapper	6	460	35	50	12	3	0
Cocoa butter wrapper	6	460	34	46	18	2	0
Vaseline wrapper	6	460	48	52	0	0	0
Paraffin wrapper	3	240	10	77	13	0	0
Common wrapper (check)	6	460	11	62	13	9	4

These data indicate that the amount of browning can be reduced by employing substances which absorb essential oils or emanating gases. Since all the tests as well as the checks were stored in identical boxes and under as nearly as possible the same conditions in the storage room, the beneficial effect of the oil wrappers must lie in their ability to prevent the accumulation of injurious substances.

This beneficial effect of gas absorbents in the control of browning is shown even to better advantage by tests with impregnated wrappers and other gas absorbents which were conducted in sealed containers. This was thought to be a more accurate method of determining the

effectiveness of these absorbents in the control of the disease, since it seemed logical to assume that there is always a considerable amount of these esters or deleterious materials in the storage room which the wrappers in the open boxes would absorb as readily as the substances from the individual specimens that are wrapped and which would soon exhaust their power to function as active absorbents. In the sealed containers, however, the absorption of substances would be more nearly confined to those given off by the enclosed fruit, which should materially increase the period of active absorption by the oils. For these experiments 33 specimens each of the same lot picked October 18, 1920, were used in each test. The results are given in table 18.

TABLE 18

THE EFFECT OF GAS ABSORBENTS ON THE DEVELOPMENT OF INTERNAL BROWNING

Treatment*	Degree of browning after 11 weeks				
	Per cent normal	Per cent trace	Per cent slight	Per cent moderate	Per cent severe
Commercial wrappers	0	6	0	59	35
Cocoa butter wrappers	65	35	0	0	0
Olive oil wrappers	53	47	0	0	0
Vaseline wrappers	65	35	0	0	0
Paraffin wrappers	25	63	12	0	0
Animal charcoal	45	52	3	0	0
Silica powder	3	3	3	44	47
225 cc. conc. potassium hydroxide in bottom of can	80	20	0	0	0
225 gr. soda lime in bottom of can	0	5	5	50	40

* All cans sealed with arrangement for slow renewal of air.

The data in table 18 show a striking correlation between the prevention of browning and the gas absorbents. In these tests 96 per cent of the treated fruit was marketable, as compared with only 5 per cent of that of the controls. The figures also indicate a definite relation between the capacity of the various absorbents for taking up esters and the prevention of the disease. Paraffin which, according to Gildemeister and Hoffman[10] has an absorbing power of approximately one-half that of the other substances, showed the least prevention of browning.

Work during the season of 1922 indicated that oiled wrappers were more effective in reducing browning early in the season. Late in the season the absorbent power of the wrappers was lost and thereafter the oil-wrapped specimens browned more severely than fruit surrounded

by common wrappers not impregnated with oil. This is logical, since the oiled wrappers more completely sealed each fruit than did the common wrapper. Furthermore, where certain oils of mineral origin were used the absorbent capacity more closely resembled that of paraffin and the effect was not so satisfactory as that obtained with the vegetable oils.

All the tests with gas absorbents, as well as those with air circulation indicate that this disease is caused by substances in the nature of essential oils or other volatile substances, which when permitted to accumulate, result in the browning. This fact would seem to place internal browning and apple scald on a similar basis with regard to causative agent.

A question which then arises is that of the appearance of scald on the surface, while internal browning develops in the flesh of the fruit. To answer this question apples were placed in sealed containers at a temperature and oxygen supply favoring the development of the diseases. In most cases it was found that scald and browning developed at a similar rate. The scald soon developed into what is termed "deep scald," while the browning rapidly diffused outward from the points of initial appearance about the vascular bundles. The generally observed appearance of scald on the surface without the internal browning and the reverse condition would then seem to indicate that these two regions of the fruit are most susceptible to the action of essential oils or other deleterious substances, or that these substances accumulate more pronouncedly in these than in any other regions of the apple. The disease appears first in that region which is most susceptible. In the Yellow Newtown the region of greatest susceptibility is in the flesh, while in those varieties that scald readily, it is at the surface.

If internal browning and apple scald are caused by the accumulation of essential oils, which can be removed by ventilation or by absorption, the question arises as to why the preventive action of ventilation and absorbents is less marked in the control of internal browning than in apple scald. This difference in the effectiveness of the prevention is undoubtedly due to the fact that apple scald is the result of the accumulation of deleterious substances on the surfaces of the fruit where the absorbent can be brought into intimate contact with them. Internal browning, on the other hand, is caused by an accumulation of the deleterious substances deep in the tissues from where they can only be removed by reducing their concentration at the surface, thereby inducing them to diffuse outward, which is a slow process.

THE INCREASE IN PERMEABILITY PRIOR TO AND ACCOMPANYING THE DEVELOPMENT OF INTERNAL BROWNING

If internal browning is due to the action of some deleterious substance which tends to accumulate in the flesh of the apple under storage conditions, there must be some evidence of its action before the browning occurs, that is, certain alterations must occur in the cells which permit the browning to take place. Possibly the most important, as well as the most probable change which could take place is that of altering the permeability.

To determine any change in the permeability which might precede or accompany the browning, measurements were made of the resistance offered to the passage of an electric current.* These measurements indicated a great reduction in the relative resistance offered by the tissue in the region of browning prior to the development of any noticeable discoloration. It was also found that the resistance continued to decrease with the detectable appearance of the disease. For example, in two representative lots of apples held at 41° F., where browning did not develop, the relative resistance was 2400 ohms; while in the same lots at 32° F., where browning did develop but before any discoloration became noticeable, the resistance was only 1100 ohms; and in apples of the same lots at 32° F. which showed trace browning, the resistance was reduced to 700 ohms.† The measurements also showed that there was no reduction in the relative resistance in fruit stored at 32° F. which was resistant to the browning.

Should this apparent decrease in the resistance be due to the action of essential oils or similar deleterious substance, the resistance of normal tissue should also decrease when treated with these oils. To test this property of these substances, several essential oils as, Amyl Acetate, Amyl Valeriate, Acetaldehyde, and others, in attenuated dilution (.001 per cent) were applied to the fruit about the electrodes of the conductivity apparatus. After the current had been on continuously for twenty minutes, the resistance of the specimens treated with water and the untreated checks dropped from 2800 to 2100 ohms, while that of the specimens treated with essential oils dropped from 2800 to 500 ohms.† The measurements show conclusively that essential oils decrease the resistance to the passage of an electric current when brought in contact with the fruit tissue. The decrease in the

* The lowering of the resistance offered to the passage of an electric current indicated a relative increase in the permeability of the cells.

† For additional data see Winkler.[19]

resistance of the untreated specimens and those treated with water was, no doubt, due to injury resulting from the continuous flow of the electric current. The data further indicate that very minute accumulations of the essential oils might be sufficient to influence the permeability of the apple cell to permit the oxidase and tannins to come in contact, thus resulting in the browning. This is especially true when the attenuated dilutions of the substances used in these tests are compared with the normal essential oil content of some apples as given by Power and Chestnut.[16] These workers have shown that the parings of the Ben Davis, an apple lacking in aroma as well as flavor, contain essential oils in sufficient amount to equal about .0007 per cent of the entire fruit, while an odorous crab apple contained .0013 per cent of essential oils.

GENERAL DISCUSSION

The fruit from trees that were vegetatively weak and also from extremely vigorous trees browned more readily than fruit from trees of normal vegetative vigor. The age of the tree exerted less influence upon the browning than the vigor. This was brought out by the fact that in 1918 and 1919, just after the young trees began to produce and when they were much more vigorous, than the old trees, the fruit of the young trees browned the more severely. In 1920, however, when the young trees had a fair crop of fruit as compared with the very sparse set on the old trees which at this time also showed the greatest vegetative vigor, the percentage of browning was greater in the fruit of the old trees.

The investigations indicate a direct relation of temperature to internal browning. Lower temperatures were found to favor and higher temperatures to oppose browning, both in the orchard and in storage. The relationship of orchard temperature to browning was most strikingly indicated in the case of the fruit in black bags and the fruit of the tented or shaded tree. In the former case the mean daily temperature, within the fruit was about 9° F. above the temperature of the fruit normally exposed, due to heat absorbed and retained within the black bags; while the fruit on the tree under the unheated tent, had a mean daily temperature of about 9° F. below that of fruit normally exposed, owing to the partial exclusion of sunlight. After five months storage, the average for the seasons of 1920–21 and 1921–22 of the black-bagged fruit was 84 per cent normal as compared with only 12 per cent normal fruit from the unheated tented tree. The normally exposed fruit browned three times as badly as the black-

bagged fruit, but much less than the fruit from the tented tree. These results point to the possibility that the mean temperature for the growing season in the Pajaro Valley hovers around the lower limit for the normal development of this variety of apple.

The results obtained with the fruit from different exposures upon the tree also indicate that orchard temperature greatly influences the resistance or susceptibility of the fruit to browning. Apples on the same tree, well exposed with regard to sunlight, browned nearly 50 per cent less than apples poorly exposed. The relation of defoliation and density of foliage to the development of browning as reported by Ballard and others[2] gives additional evidence in attributing the susceptibility to browning of the apples of this valley to the low temperature during the growing months. These workers state that apples from partially defoliated branches browned less than fruit from the same trees on branches carrying all their foliage. They also found that fruit from trees of unusually heavy foliage browned more severely than that from trees with only a moderate amount of foliage. Their figures on the analyses of this fruit indicate that neither defoliation nor the different amounts of foliage influence the nutrition of the fruit with respect to sugar or acid content sufficiently to account for its different behavior with regard to the browning when placed in storage. Even though Ballard and others[2] give no indication as to why the defoliation and the moderate foliage as compared with heavy foliage proved beneficial in reducing the browning, the writers believe that these conditions of foliage permitted more direct sunlight to fall on the fruit thereby increasing the temperature. This indication is substantiated by the fact that in 1908 and 1914, when the mean temperature for the growing months was a few degrees below the average mean temperature for these months for the last seventeen years, the browning was very severe. On the other hand, in 1912, 1913, 1917, and 1918, when the mean temperature was several degrees above the average mean temperature for the growing months, there was very little or no browning. This marked effect of the temperature upon the browning was brought out more strikingly in storage. For example, at 30°, 32°, 36°, 40°, and 45° F. the percentage of normal fruit after four months storage was 10, 15, 35, 74 and 95 per cent, respectively.

In view of the above correlation of the browning with lower mean temperatures it also seems possible that the more severe browning of the mature fruit was due to its being exposed to the lower temperature which prevailed during the latter part of the harvesting season. The fruit of the second picking was exposed for three weeks after the fruit

of the first picking was harvested to a mean temperature of about 4° to 5° F. below the mean temperature of the growing season. The fruit picked November 6 and November 22 was exposed for six to eight weeks to the influence of a mean daily temperature of 4° to 14° F. below that prevailing at the time and before the first picking was made. The fruit of the 1922 season, which was harvested fully a month later than the normal harvest season, browned more severely in storage than either of the two preceding crops. These data point to the possibility that the low temperature favors those conditions within the fruit which are necessary for the development of browning. This weakness in the fruit, however, if it can be considered as such, may be due to an abnormal development of the protoplasmic structure of the apples or to an accumulation of some deleterious substance which brings about a more rapid cessation in the normal functioning of these structures in storage. This seems probable since there was no appreciable difference between the fruit resistant and that susceptible to browning in those constituents such as sugars and acid and the pH value of the expressed juice, which might be expected to influence a reaction of this sort.

The accumulation of essential oils or similar deleterious substances also seems to be linked with the weakness which shows up in these apples in storage. This is indicated by the great reduction in the amount of browning that is brought about through the employment of air circulation or the impregnation of the wrappers with good absorbents for these substances. It has been further demonstrated that the permeability of the cells, which is the most probable change that might precede this browning or similar reactions, is increased rapidly by essential oils when applied even in great dilution to the apple tissue. It was also found that there was an increase in permeability prior to the death of the cells in the apple regardless of whether death was due to the usual type of storage breakdown that is the result of overripening, or to internal browning.

The data obtained upon the relationship of temperature and the accumulation of essential oils or similar volatile substances to the browning, although not conclusive, point to several possibilities concerning the cause of this disease. When these apples are grown at a mean temperature as low as that of the growing season of the Pajaro Valley, they fail to develop normally, hence when they are placed in storage the flesh of the fruit exhibits a susceptibility to injury through the action of the volatile emanation of the apple. This is indicated by the behavior of the fruit from different regions as well as by that from under the tent and from the black bags. The lower temperature may

not only affect the development of the fruit, but it also seems to influence the production or accumulation of the volatile substances which are immediately responsible for the browning. This becomes apparent when the great difference in the amount of browning which developed at the several storage temperatures is taken into account. At the lower temperatures there must be a greater production of these substances or else they must accumulate more rapidly in those regions of the torus that are first to show the browning. The reduction in the development of the browning by the use of gas absorbents also indicates that these volatile substances are present in injurious amounts at the lower temperatures under the ordinary conditions of storage. The more rapid accumulation of the deleterious substances may seem the more probable way of accounting for the injurious amount of these substances when the decrease in their volatility and the decrease in the permeability of the tissue at the lower temperatures is considered. It is, however, not at all unlikely that there is also a greater production of these substances under the somewhat abnormal conditions of the lower temperatures of storage.

The nature of the process which results in the browning becomes of interest in connection with the above possibilities as to the cause of this trouble. A plausible explanation of this process would be to attribute it to an increase in the permeability of the protoplasm which permits the enzymes and their substrati to mix. These changes might be brought about by the accumulation of certain substances as the essential oils which are produced by the apple in storage, and which apparently have a toxic effect upon the protoplasm of the cells. In the normal cells, the enzymes are prevented from acting upon their substrati through lack of contact due to the possible impermeable nature of the phase surfaces of the protoplasm to these substances. When the phase arrangements in the protoplasm, however, are acted upon by toxins, these substances are no longer prevented from coming into contact. As a result of this liberation, the tannins of the apple cells may be oxidized to a brown by the oxidase present in the mature fruit. It has been indicated by Bartholomew[3] that similar changes precede the blackening of the tissue in ''Blackheart'' of potatoes. This explanation of the coloration as based upon a change in the permeability is also supported by the fact that before browning occurs there is a great increase in the permeability of the cells as indicated by the conductivity measurements.

SUGGESTIONS FOR THE CONTROL OF INTERNAL BROWNING

Since the temperature that prevails in the Pajaro Valley during the growing months and which cannot be controlled, seems to be the potent factor in rendering the Yellow Newtown susceptible to browning, it becomes necessary to control the development of this trouble after the fruit reaches maturity. Should this be true, there are two ways open for a solution of the problem. The first, which would aim at a direct control, consists of the employment of those practices which prevent the further development of the disease in storage. A second solution, which is indirect, would consist in supplanting the Yellow Newtown with a variety that is not so seriously affected by the low temperature of the growing months of the Pajaro Valley.

Early Harvesting as a Means of Controlling Internal Browning.—Apparently the first step in the control of this trouble after the fruit reaches maturity is that of harvesting the crop as early as possible. The low mean temperature seems to be involved in rendering these apples susceptible to browning. Hence, the fruit which is permitted to remain on the trees until late in the season, when the mean temperature is much below that of the growing months, might be expected to brown more readily. The records of several seasons during which tests have been in progress, indicate that this is what happens. For example, each of the pickings of September 27, October 16, and November 6, 1920, showed approximately 60 per cent of marketable fruit after 20, 15 and 6 weeks storage, respectively. These figures represent the results obtained from fruits of the same trees stored at 32° F. In fact, all the data collected in connection with the different dates of harvesting indicate that it would be a desirable practice for the growers to harvest their fruit as soon as possible after it is sufficiently ripe for picking.

Storing Apples at 37° to 40° F. to Control the Browning.—The most promising method for the control of browning, after the fruit is harvested, is that of prompt storage at temperatures of 37° to 40° F. The practice of delayed storage or even a delay in getting the fruit into storage has in all tests increased the subsequent amount of browning. With prompt storage at the above mentioned temperatures the percentage of browning on April 1, after six months storage, was less than 15 per cent and the browning that did occur was of a mild nature which would not interfere with the commercial value of the fruit.

Fruit from the same trees stored at 32° F. showed 100 per cent of browning before this time, 60 per cent of this fruit being so severely browned as to render it unmarketable. In this connection, however, the question arises as to whether the loss through rot at these temperatures might not be sufficient to off-set the benefit derived from the avoidance of browning. This would, no doubt, be the result with many varieties of apples if they were stored at 37° to 40° F. The Yellow Newtown, however, is one of the best keepers, and when stored at these temperatures during the past two years there was practically no rot, even though the fruit was tree-run and had not been sorted.

Ventilation in Storage as a Means of Controlling the Browning.—A second method whereby the development of the browning may be controlled in storage is that of ventilation. This method may be of value where the storage facilities are such that it becomes necessary to store these apples below 36° F. The unwrapped fruit, stored at 32° F. and ventilated before a fan for 10 to 20 minutes twice each week showed only 14 per cent of mild browning on April 1, compared with 76 per cent of browning for the fruit in ordinary commercial storage, 13 per cent of the browning in the latter case being of such severity as to render the fruit unfit for consumption. Further experiments will be necessary, however, before definite recommendations can be made for the use of ventilation to prevent browning.

Predicting Browning Prior to Storage.—As indicated by the results of this investigation, the mean temperature of the growing months appears to be the potent factor in rendering the Yellow Newtown apple susceptible to browning. If future studies substantiate this apparent relationship of orchard temperature to browning, it should then be possible, by consulting the Climatological Data Reports of the U. S. Weather Bureau for the growing months, to predict the approximate amount of browning which will occur during the storage season of these apples. In years of possible severe browning, growers could dispose of their crop early and avoid loss through this disease. When little or no browning threatens, the Yellow Newtown could be stored and the profit secured from a late-keeping variety of the best quality and flavor.

Elimination of Browning Through More Resistant Varieties.—An indirect method of overcoming the difficulty of browning would be to supplant the Yellow Newtown with some variety that is not so seriously affected by the low temperature of the growing months of the Valley. This method of solving the problem, however, is not as readily carried out as might appear on first thought. Mr. Rodgers,

the father of the Rodgers brothers from whom the fruit for these tests was obtained, undertook to find a variety which could be used to supplant the Yellow Newtown. He introduced a great number of apple varieties of commercial importance and was finally forced to the conclusion that the Yellow Newtown and the Yellow Bellflower are the only commonly known varieties that produce profitably under the climatic conditions of the Pajaro Valley. Nevertheless, it may yet be possible to find a variety that will take the place of the Yellow Newtown, although this will require years of searching and the testing of a great number of varieties. In view of the present effort in bud selection, it may be possible to isolate a strain of Yellow Newtown which is resistant to browning. The Yellow Bellflower might be planted more widely since it is a fall apple, and as a result, is consumed before losses due to browning occur. The Yellow Bellflower, however, ranks below the Yellow Newtown in quality, yield and appearance, and cannot be expected to supplant the Yellow Newtown.

SUMMARY

1. Internal browning is a non-parasitic disease of the large isodiametric cells of the flesh of the fruit.

2. Yellow Newtown apples, regardless of where grown, have been in some years, susceptible to internal browning. Nevertheless, this variety when grown under the conditions prevailing in the Pajaro Valley, is more susceptible to this disease than when grown in other fruit regions.

3. The results of the studies showed a relation between tree age and internal browning; fruit from old trees browned more severely than fruit from young trees. Differences in the maturity of fruit from old and young trees at harvest time probably affected the degree of browning.

4. Fruit from trees bearing a heavy crop was less susceptible to browning in storage than fruit from trees bearing a light crop.

5. Fruit from trees of normal vegetative vigor exhibited the most resistance to browning; fruit from trees vegetatively weak or from trees of extreme vegetative vigor was more susceptible to browning. The decrease in resistance, however, was most marked in the fruit from the very weak trees.

6. The degree of browning increased in severity with the maturity of the fruit; that is, the later the fruit was picked, the greater the

amount of browning which occurred in storage, and the more rapidly it developed.

7. Chemical analyses of the fruit indicated that there was no relation between the sugar and acid content of the apples and their resistance or susceptibility to this disease.

8. No relation was found to exist between the amount of browning and the pH value of the expressed juice of the apples.

9. A lowering of the mean orchard temperature of about 5° F. during the growing season, by tenting or shading a tree, greatly increased the susceptibility of the fruit to browning. After five months storage at 32° F. the fruit of trees in unheated tents showed 50 per cent less normal specimens than that of adjacent trees which were normally exposed.

10. An increase of 10° F. in the mean orchard temperature by bagging individual apples in black cloth during the growing months, markedly increased the resistance of the fruit to this disease. The bagged apples showed two-thirds more normal specimens after five months storage at 32° F. than the normally exposed fruit of the same trees.

11. Fruit from the interior shaded portions of the tree browned twice as badly as fruit from the exposed portions of the tree where the temperature was 14° F. higher.

12. Some evidence was obtained to show that self-pollination and cross-pollination are factors which do not materially affect the development of browning.

13. Delayed storage rendered the fruit more susceptible to browning.

14. Intermittent storage gave no promise as a means of control of this disease.

15. No serious browning occurred even after five months storage in the fruit stored at 45° F. or above.

16. The browning at the end of six months' storage at 40° F. was limited and mild, and insufficient to interfere with the commercial value of the fruit.

17. At 36° F. approximately 65 per cent of the apples showed browning by April 1, during each of the seasons for which records are available.

18. At 32° F. nearly all of the fruit showed browning by April 1, or shortly thereafter, each season.

19. It was shown that the accumulation of carbon dioxide in the storage rooms does not favor browning. In fact, the storage of the fruit for several days in pure carbon dioxide increased its resistance to the disease.

20. An increase in the oxygen supply did not oppose browning.

21. Browning was greatly reduced by ventilating the fruit. This treatment was equally effective regardless of whether the ventilation was rapid and intermittent or slow and continuous.

22. The browning was reduced during the early part of the season by impregnating the wrappers with oils and waxes which are good absorbents of essential oils. Oils of low absorbent capacity increased the browning by preventing the escape of the emanations.

23. By measuring the electrical resistance of the apple tissue, it was found that there was an increase in permeability prior to the end of the storage life of the apple, regardless of whether death was due to the usual storage breakdown or to internal browning.

24. It was demonstrated that essential oils when applied to the apple tissue, even in great dilution, rapidly increase its permeability.

25. The data indicated that internal browning is due to the accumulation of essential oils or similar deleterious substances which are produced by the apples in storage. This signified that internal browning and apple scald were quite closely related with respect to cause.

26. Hypotheses have been offered in explanation of the nature of browning and the greater susceptibility of the Yellow Newtown apple to the disease when grown under the conditions that prevail in the Pajaro Valley.

27. Practical suggestions for the control of internal browning have been given.

ACKNOWLEDGMENTS

The writers wish to acknowledge their indebtedness to Professor J. C. Whitten for suggestions and criticisms given before his untimely death, and to Dr. J. P. Bennett for counsel during the progress of this investigation.

Furthermore, the writers are indebted to Professor R. H. Taylor for preliminary work during the season of 1917–18; to Messrs. S. H. Cameron and J. L. Fidler who assisted during seasons of 1921–22 and 1922–23, respectively; and to Mr. L. P. Latimer who was responsible for the temperature control during 1921 to 1923, inclusive.

BIBLIOGRAPHY

[1] ARMSTRONG, H. E., AND ARMSTRONG, E. F.
1910. The function of hormones in stimulating enzymatic change in relation to narcosis and the phenomena of degenerative and regenerative change in living structures. Pt. III, Proc. Roy. Soc., B. 82, p. 588.

[2] BALLARD, W. S., MAGNESS, J. R. AND HAWKINS, LON A.
1922. Internal Browning of the Yellow Newtown Apple. U. S. D. A. Bull. No. 1104, pp. 1–24.

[3] BARTHOLOMEW, E. T.
1914. A Pathological and Physiological Study of the Black Heart of Potato Tubers. Centrbl. für Bakt. Zw. Abt. Bd. 43, pp. 609–638.

[4] BROOKS, C. AND COOLEY, J. S.
1917. Effect of temperature, aeration and humidity on Jonathan-spot and scald in storage. Jour. Agr. Res., Vol. XI, No. 7.

[5] BROOKS, C., COOLEY, J. S., AND FISHER, D. F.
1919. Apple-scald. Jour. Agr. Res., Vol. XVI, No. 8.

[6] BROOKS, C., COOLEY, J. S. AND FISHER, D. F.
1919. Nature and control of Apple-scald. Jour. Agr. Res., Vol. XVIII, No. 4.

[7] DIXON, H. H., AND ATKINS, W. R. G.
1913. Osmotic pressures in plants. I. Methods of extracting sap from plant organs. Proc. Roy. Dubl. Soc. 13 (n. s.), p. 422.

[8] GIGLIOLI, I.
1911. Della probabile funzione degli olii essentiali e di altri prodotti volatili delle piante, quale causa di movimento dei succhi nei tessuti viventi. Rendic. R. Acad. Lincei., Vol. 20, ser. 5*a*, p. 349.

[9] GIGLIOLI, I.
1912. Une methode nouvelle et simple pour separer la zymase de la levure de biere, et pour extraire generalement les enzymes des tissues vivants. Arch. Ital. Biol., Vol. 58, fasc. 3.

[10] GILDEMEISTER, E., AND HOFFMAN
1913. The volatile oils. 2nd Ed. (Trans. by Kremers, E.).

[11] MACKIE, W. W.
1911. Soil survey of the Pajaro Valley, Calif. U. S. D. A. Bur. Soils, 10th Rept., pp. 1331–1372.

[12] OSTERHOUT, W. J. V.
1913. The effect of anaesthetics upon permeability. Science, Vol. 37 (n. s.), p. 111.

[13] PANTANELLI, E.
1919. Alterazioni del ricambio e della permeabilita cellulare a temperature prossime al congelamento. Atti R. Accad. Lincei Rend. (Cl. Sci. Fis. Mat. e Nat.) Vol. 28, pp. 205–209.

[14] POWELL, G. H., AND FULTON, S. H.
1903. The apple in cold storage. U. S. Plant Indus. Bur. Bull. 48.

[15] POWELL, G. H.
1909. Internal browning of apples. Ice and Refrigeration, Vol. 36, No. 1, pp. 8–9.

[16] POWER, F. B., AND CHESTNUT, V. K.
1920. The odorous constituents of apples. Emanation of acetaldehyde from the ripe fruit. Jour. Agr. Chem. Soc., Vol. 42, p. 1509.

[17] STUBENRAUCH, A. V.
1910. (Cold storage investigations) U. S. Plant Indus. Bu. Rept., pp. 78–79.

[18] STUBENRAUCH, A. V.
1912. Fruit Handling, Precooling and Storage Investigations. Ice and Refrigeration, Vol. 42, No. 1, pp. 34–36.

[19] WINKLER, A. J.
1923. A Study of the Internal Browning of the Yellow Newtown Apple. Jour. Agr. Res. Vol. XXIV, No. 2, April 14.